ARM Vision 2000

As Seen by the

ARM Cloud Parameterization and Modeling Working Group

prepared by the Steering Committee:

David Randall, Steve Krueger, Tony Del Genio, Steve Ghan, Minghua Zhang, and Ric Cederwall

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Executive Summary

The Cloud Parameterization and Modeling (CPM) Working Group (WG) has assessed the current state of the ARM Program, both what is going well and what could be better, and offered recommendations on how to move forward over the next 3-5 years. We have done this from our WG perspective, and provide our input, along with that from other WGs, in response to the ARM Scientific Director's request for input to help him assess the scientific state of the program and plan for its future.

The ARM Program is now a decade old, and is at a critical point in its life. A substantial, and well-recognized, foundation of data collection capability, technical infrastructure, funded investigators, and outside collaborations has been built over this time. We believe that it is time to move from building the program to harvesting the fruits of the program's labors. The CPM WG plays a pivotal role in carrying out ARM's goal to improve cloud and radiation parameterizations in large-scale models through the collection of relevant data under climatologically diverse conditions. Our WG is positioned as the interface between the measurement and detailed process side of the ARM Program, and the planned beneficiaries of the ARM Program, namely the climate modeling community.

The ARM Program has accomplished much over the past decade. From our WG perspective, we see that the high-quality ARM data and technical infrastructure have provided incentives for successful collaborations between ARM scientists and numerous cloud and radiation parameterization groups, as well as the cloud-system modeling community. Our WG has been the catalyst for much of this, and this has substantially increased ARM's ability to address one of its central thrusts: the development and evaluation of cloud process parameterizations. We have effectively integrated our Single-Column Model and Cloud-Resolving Model efforts for the testing of cloud parameterizations using ARM data; our collaboration with GCSS has accelerated this process.

We see several areas needing improvement so that our WG can move forward faster. Most important, the ARM data need to be processed to provide more data sets with direct utility for the modeling community. This includes cloud and radiation data products that describe the spatial/temporal distribution within the atmospheric column, as well as the rates of large-scale advection of cloud water and ice into the column. We need to focus on key scientific issues that concern a broad set of modelers. Examples of these are cloud cover parameterization, convective triggering, liquid-ice transition, treatment of downdrafts, and the development/maintenance of cumulus anvils. Finally, we need to continue to provide an environment in ARM that stimulates the generation of ideas, not just the mechanistic production and analysis of ARM data sets.

The ultimate measure of success for the ARM Program is the degree to which the ARM data and scientists contribute to improved radiation and cloud parameterizations in GCMs and NWP models. We have a unique opportunity to foster the development of those parameterizations, and to test them with ARM data. ARM has demonstrated a new way of conducting a major research effort over a long time period. We will be judged on how well we capitalize on the data and talent assembled in the ARM Program, and on the long-term utility of the ARM legacy data sets to the general scientific community.

1. Introduction

This document is a “vision statement” from the ARM Working Group (WG) on Cloud Parameterization and Modeling (CPM). It has been prepared at the request of ARM Program management. It provides an assessment of the current state of ARM, suggestions for improvements of the program, and ideas for how ARM should evolve over the next five years or so.

2. An assessment of the present state of the ARM program in terms of its scientific objectives -- an assessment of the present state of the science

ARM has set itself up to solve the cloud-radiation-climate problem, but it can't do that. The cloud-radiation-climate problem will not be solved on a certain day. In this way it is fundamentally different from decoding the Human Genome, for example. The cloud-radiation-climate problem is yielding gradually, bit-by-bit, in a process that is going to take many years.

According to the ARM Science Plan, the programmatic focus of ARM is on the development and testing of parameterizations of important atmospheric processes, particularly cloud and radiative processes, for use in general circulation models (GCMs). ARM therefore places strong emphasis on development and testing of cloud and radiation parameterizations for use in GCMs.

The scope of research aimed at improving cloud parameterizations is very broad because cloud processes are very diverse. The development and testing of improved parameterizations of cloud formation and dissipation is by far the most difficult objective of the ARM program. Although the parameterization of radiative transfer presents its own challenges, particularly for the partly cloudy atmosphere, the parameterization of the subgrid spatial distribution of cloud microphysical properties and processes requires the representation of a wide variety of subgrid dynamical, thermodynamical, and microphysical processes that interact and are all important under the wide range of large-scale conditions that arise in the atmosphere. This fact has been widely recognized from the beginning of the program, but it bears repetition.

From ARM's perspective, the most important mode of parameterization testing is the direct confrontation of parameterizations with ARM data.[1] In order for ARM to succeed it must, therefore, collect data suitable for use by the worldwide community of parameterization developers, parameterization users, and parameterization testers. In addition, ARM must find ways to ensure that the data is actually used by that community.

Finally, ARM should directly support the development of improved cloud and radiation parameterizations.

The ultimate measure of ARM's success is the use of improved radiation and cloud schemes for GCM simulations and numerical weather prediction. When the ARM program is judged, it should be judged on the extent to which it has fostered the development of new cloud and radiation parameterizations and the testing of those parameterizations with ARM data. ARM should not, however, funnel money to modelers just for GCM development, regardless of the presence or absence of ARM data streams that would be helpful in the process.

Although global simulation and prediction can be used to examine, test, and improve parameterizations, this should not be ARM's main approach. What ARM can directly contribute is data collected at local sites. The challenge is to usefully connect these local data with global models. ARM's link to the community of parameterization developers is the CPM WG. A summary[2] of the progress and plans of this WG was prepared in late 1998, and should be considered as an important background document for the current vision statement. This document

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1. Of course, parameterizations also have to be tested in other ways, e.g. through numerical weather prediction and climate simulations.
2. ARM Single-Column Modeling: The Next Five Years. Prepared by the ARM SCM Working Group, with major contributions from David Randall, Ric Cederwall, Steve Ghan, Tony Del Genio, Steve Krueger. October 1998. Available at `http://www.arm.gov/docs/scm/documents/whitepaper_98.pdf`.

is available via the web on the WG web page (`http://www.arm.gov/docs/research/scm.html`) under Publications.

The following is a succinct summary of the status of the CPM WG as it relates to the goals of ARM discussed above.

Things That Are Going Well

- ARM is unique in the history of the atmospheric sciences, and has raised the bar in many ways. ARM has collected a long time series of data suitable, after processing and integration, for testing cloud and radiation parameterizations. The duration of the field operations is itself a major and very valuable innovation. The ARM Infrastructure is another successful innovation; to our knowledge, nothing similar has been set up for any other research program in the atmospheric sciences. In addition, ARM has been unusually successful in forging cooperative efforts with other programs.

- ARM has obtained additional very useful data from a variety of sources. This includes temperature and moisture soundings, wind profiles, surface radiation, cloud data and retrievals from various instruments including the cloud radar and the microwave radiometer, and surface fluxes of sensible and latent heat meteorological data from the Oklahoma Mesonet and radar-based precipitation data from NOAA's Arkansas Red Basin River Forecast Center, Earth radiation budget data from NASA, and numerical weather prediction products from ECMWF and NECP. At present these data are available primarily from the SGP site, although the data streams from the TWP and NSA sites are ramping up.

- The ARM infrastructure, together with members of the ARM Science Team (ST), have succeeded in producing high-quality value-added (i.e., integrated) data products suitable for driving models and evaluating model results, thus enabling the testing of parameterizations.

- ARM has organized and entrained the world modeling community and has defined several approaches for evaluating radiation and cloud parameterizations. In particular, CPM WG has attracted the participation of numerous members of the cloud and radiation parameterization community, as well as the cloud-system modeling community. Participating modeling centers include NCAR, ECMWF, and NCEP. This is good. On the other hand, ARM should not be funding modelers just for GCM development, regardless of whether or not ARM data is being used.

- The CPM WG has entered into an alliance with GCSS (the GEWEX Cloud System Study). This has led to the use of ARM data by a large additional group of cloud and radiation modelers and parameterizers, including many non-U.S. scientists.

- It is the perception of the community that the ARM data products disseminated by the CPM WG are of particularly high quality relative to other datasets which have been used to test parameterizations in the past. Important strengths of the ARM data include the wide variety of measurements, and the ongoing accumulation of a large number of cases which can be used to test parameterizations in a wide variety of ways.

- ARM data has in fact been used in the testing of many new parameterizations, and this is continuing.

Things That Could Be Better

- The CPM WG's efforts to date have been hampered by the lack of information about large-scale advection of cloud water and cloud ice into the CART site column. We need to work closely with the Cloud Properties WG to define measurements and algorithms that will provide a best estimate of these quantities within the next year. It is clear that in the continental midlatitudes, the advection of cloud properties is an important forcing in the column. The lack of this information seriously limits the use of CPM WG studies in parameterization evaluation.

- To date the bulk of the attention in ARM data analysis has been at the instrument level, and focused on process studies. With the exception of the variational analysis efforts, ARM has done little to fuse and integrate ARM data (and external data) into data sets useful for large-scale modeling. ARM has in fact made some progress in producing integrated datasets that can be conveniently used by the community, but only for a very small fraction of the data collected, and so far only data to drive/evaluate SCM/CRMs. ARM has not been sufficiently effective in assembling various quality-controlled data into products that can be easily used. For example, ARM should be routinely or "operationally" producing packaged data for testing GCM radiation codes offline, as well as packaged cloud products. ARM should be releasing data on CD-ROMs, as well as via the Web.

- Right now, we don't have the data needed to test parameterizations of subgrid microphysical processes. As a result we don't know whether or not we have useful ideas about how to approach the problem. We'd like to *get* some ideas from the data!

- We need to continue to extend our capability to compare model results with data. We need to approach this in two ways: (1) process observations into data sets compatible with model fields, and (2) process model output into observation-like quantities. We have spent most of our effort on the first approach (and need to continue that effort), but we need to make more progress on the second approach. Some instrument data streams are more amenable to comparison using the measured quantities than manipulating the observations into values like the modeled quantities. Where this is true, the CPM WG needs to collaborate with those inside ARM, and beyond ARM where necessary, to bring knowledge of measurements together with modelers to process model output into data sets that can be compared more directly with measurements.

- At present the data streams from the NSA and TWP sites are not sufficiently comprehensive to permit extensive tests of cloud and radiation parameterizations. Nevertheless we recognize that those sites are compiling valuable statistics of cloud properties that will be useful in understanding model behavior.

- Although the SGP *data stream* is comprehensive, much of it is not yet available in terms of usable cloud products.

- The IOPs needed to support the CPM WG's activities are quite expensive, largely because of the need to purchase many expendable sondes, and supporting the associated labor to launch them.

- ARM has not succeeded in collecting data on the vertical profiles of radiative fluxes. From an observational point of view this is perhaps one of ARM's main shortcomings.

- Insects at the SGP site have made low cloud detection by the MMCR virtually impossible during the spring and summer months, thus reducing the usefulness of the cloud radar for testing models.

- The ARM data on the surface fluxes of sensible and latent heat is not as good as it needs to be. These fluxes are very important for driving cloud formation over the SGP site.

- The CPM WG has not yet produced any "high-profile" scientific breakthroughs. As difficult as cloud parameterization is, the evaluation of cloud parameterizations may be even more difficult. The pace of progress in the parameterization of clouds in climate models is to a large degree controlled by the limitations of our understanding of cloud processes. A complete parameterization of the subgrid spatial distribution of cloud microphysical properties and processes could increase the computation time of a climate model two to five-fold, and hence must be thoroughly justified by a demonstrated superiority compared with simpler parameterizations. If we ask *why* ARM hasn't yet produced radically improved parameterizations, we can suggest four reasons:

    (1) The cloud-radiation data sets really do not exist yet for the most part. There are disconnects between different parts of the project as to whose responsibility it is to provide data to CPM in usable form. There are very few cloud data sets available at the SCM Web site. The only cloud radar data sets are for cloud boundaries - none of the LWC, IWC, particle size information we always hear about at the ST meetings is actually available yet. We have heard of a 2-year cloud-optical-thickness dataset, but it is not yet available to the CPM. Are there any radiation profiles yet? This is partly a

communication problem, and partly a problem for ARM management. On the communication side, we as a WG need to reiterate the specific parameters and time periods we'd like to have, along with a basic description of how the data should and should not be used. The time periods are just the ones we have IOPs for, listed in the priority order previously determined by the CPM WG. We need cloud optical thickness data, liquid water and ice water content profiles, particle sizes, upper troposphere water vapor, and a better cloud base product. These data should be accompanied by a suitable "users guide", giving a basic description, and caveats such as daytime only, good only when isolated cirrus exist with no mixed phase, no precipitation, etc., or that particle sizes are for precipitating ice particles only, or that an error bar of x% is appropriate, etc. The modeler needs enough information to figure out how a simulation should be sampled for comparison with the data, and how close to the data is close enough to be "good"?

(2) We haven't figured out how to deal with the remaining effects of forcing errors in assessing our results. Despite Minghua Zhang's heroic efforts, forcing errors still remain, and we need to develop a strategy for assessing parameterization errors in a modeling system which retains some "garbage-in" characteristics. Statistics from many IOPS is one way around this; there may be others. But we need to get past the comparison of two squiggly lines and "well, the model doesn't look too bad compared to the data" types of talks, and decide what our metrics are going to be (and why) for climate model improvement.

(3) We haven't yet focused on a few science issues of concern to a broad cross-section of modelers. Each of us is free to use ARM to test any aspect of our models that we want. But we need to go beyond Scientist A improving element A of his cloud scheme, Scientist B improving some other element B of his scheme, etc. What we need is to identify a few outstanding parameterization questions that cut across the whole community of modelers, and preferably questions that we can easily argue are important to our ability to predict climate change; also, preferably, questions to which ARM data can speak, or at least to which CRMs forced with ARM data can speak. Here are a few examples:

- *Cloud cover parameterization:* We need to understand the variety of subgrid-scale pdfs of cloud properties under different environmental conditions and whether the shapes and widths are easily parameterizable. Doing this gives us a physically-based cloud fraction while also allowing us to tackle the cloud water path - to - albedo problem and the issue of nonlinearity of microphysical process parameterizations.

- *Convective triggering:* On the surface this is a poor match to ARM, which is about clouds and radiation and is not particularly interested in cumulus parameterization. However, the forcing data sets may be a useful testbed for looking at this problem. The suppressed conditions of Nauru '99, rather than being viewed as a disappointment, may be a good test for us to see whether our cumulus parameterizations go off when the real world says no. And ultimately, getting convection to occur at the right time is important for the clouds that result.

- *Liquid-ice transition:* Very different assumptions are made in different GCMs, affecting cloud cover feedback. MMCR can surely give us some insight into this, perhaps in combination with satellite instruments such as POLDER, which have already been used to look at this for an SGP case.

- *Downdrafts:* Again, not an obvious match for ARM, but Steve Krueger's CRM-SCM comparison indicates there's work to be done there, and we know that downdrafts are important.

- *Cumulus anvils:* The best way to argue for convection research under the ARM umbrella is to pay attention to the clouds the convection produces. We are not ready to say that we know how to simulate the transport of condensate in convective updrafts into anvils, much less the mesoscale production of ice by the anvil itself. An interesting test for the sub-community of modelers with prognostic TKE.

(4) Very few people in ARM are trying to use the data to do basic cloud/radiation science that is the necessary foundation for improved parameterizations. Up to this point, ARM has taken too much of an engineering, product-oriented approach. The project is not sufficiently idea-driven. Imagine the following scenario: Ten years of ARM data have been collected, but ARM itself no longer exists as a funded program. An agency like NSF comes along and invites proposals to use the data to do any kind of interesting science possible - no pressure to accurately compute radiative fluxes, no pressure to develop/test parameterizations. What science would be proposed? A certain amount of activity of this type is needed in any program, and ARM does not have enough of it.

- Until very recently, the CPM WG has been focused almost exclusively on case preparation and intercomparison exercises, rather than scientific issues associated with particular parameterizations. This was necessary as a "developmental stage," but we have to move on now. One of the primary difficulties involved in improving cloud parameterizations is that they strongly interact with many other parameterizations (i.e., those for radiation, cumulus convection, turbulence, boundary layer, and surface fluxes), as well as with the large-scale circulation. As a consequence, a change to any aspect of a SCM or GCM is likely to affect the clouds, and an improvement to the cloud parameterization itself may not actually improve model results.

3. How improvements can be made over the next three to five years

The success of ARM largely depends on its ability to interact with large-scale modelers. Incorporation of parameterization improvements in large-scale models is only one measure of ARM's success, one that ARM actually has little control over, though the ARM Fellows will certainly aid in this effort. Another measure of success is making the integrated datasets produced by the CPM easily accessible. These datasets could include consensus CRM results as well as the processed ARM observations used for testing SCMs. The relationships between cloud properties determined from ARM observations would also be a useful product.

SCM IOPs have been a valuable component of the ARM measurement strategy for supporting SCM/CRM efforts. These IOPs have also been well-leveraged with other ARM IOPs. In the future, however, SCM IOPs should be driven by specific scientific objectives. We need to focus more by putting some emphasis on the understanding and parameterization of particular processes. For example, fractional stratiform cloudiness can be formed through gravity waves, decaying shallow convection, frontal systems, etc. These and other specific cloud-formation mechanisms can be targeted in future IOPs, designed to address particular parameterized processes. What we are trying to get out of each IOP should be identified so that the design of the IOP (length of days, season), as well as the scheduling with other IOPs, will give us the maximum return for the resources expended. For example, having our most recent SCM IOP with the March 2000 Cloud IOP supports the objective to quantify the spatial distribution of cloud properties, and to evaluate the utility of time-averaging data and retrieved cloud quantities from the cloud radar at the Central Facility to represent spatial statistics needed for SCMs and CRMs.

The ARM program has heavily relied upon (and invested in) the single column model as the primary testbed of cloud parameterizations at the ARM sites. Although substantial progress has been made in demonstrating that SCMs in combination with ARM data are a viable cloud-parameterization testbed, it is time for the program to consider additional parameterization testbeds. The evaluation of cloud parameterizations in SCM simulations continues to be confounded by the uncertainty in the lateral boundary conditions and limited by the inability of SCMs to represent the feedback of the simulated heating on the circulation.

One alternative testbed is of course climate simulations with GCMs. The use of ARM measurements for the evaluation of climate simulations is highly inefficient for two reasons. First, such simulations span the entire globe while the ARM measurements cover only a tiny fraction thereof. Second, climate simulations can be compared with measurements only in a statistical sense, and hence do not make full use of the highly detailed ARM data. Nevertheless parameterizations can only be fully tested through their use in climate simulations, and ARM must ensure that ARM-developed parameterizations are in fact being tested through climate simulations.

A second alternative testbed is numerical weather prediction. Collaborations with both ECMWF and NCEP have been initiated by the ARM program, and, at the instigation of the CPM WG, ARM has recently established the ARM Fellow program which will place ARM-sponsored scientists at both NCEP and ECMWF. We have yet to see the fruits of this initiative, which is just getting under way.

We now provide a brief list of additional changes in ARM's *modus operadi* which would, in our view, contribute to the continuing and enhanced success of the program:

- The State of ARM Science is not assessed frequently enough. We need at least an annual look at where we are in accomplishing the scientific objectives of ARM and a clearer statement of what we want to accomplish in the next year. The current request for input appears to be a good start. The ARM Program is in its payoff or harvesting years after a decade of building (or growing) a large measurement capability, observational database, knowledge infrastructure, and, most importantly, a team of principal investigators and outside collaborators familiar with the ARM data and the scientific objectives of the program. An annual assessment would allow us to: (1) identify the accomplishments of the past year (i.e. finally cross off some objectives on our list), (2) set near-term goals for the program so that resources can be made available during the budget cycle, (3) revisit long-term goals and ARM scientific objectives so that we can decide where efforts can be discontinued and where new efforts need to be initiated, (4) identify gaps in the scientific capacity of ARM so that we can fill those gaps by (a) the ARM proposal selection process, (b) establishment of collaborations, (c) IOPs, and (d) directed infrastructure activities, and (5) more effectively communicate what we have done and where we are going to DOE management, other research programs, and the general scientific community. We have got to do a better job of promoting ARM.

- The CPM WG can take a leadership role in defining the types of data that should be packaged for various parameterization components (not just for the SCMs and CRMs), because we are the group that is closest to the parameterizations. These data sets should be produced with end users in mind. ARM has not done enough to produce quality, easy-to-use integrated data sets packaged for testing various parameterizations. The Data Integration subgroup in the CPM WG is one key place to start. We will need to work closely with experts in the other WGs; we are the ones that know best what the end product must be, however. Such integrated data sets will do much to stimulate collaborations with the large-scale modeling community who are the ultimate beneficiaries of ARM successes in improving process parameterizations. In particular, we have the opportunity to work closely with NWP reanalysis activities, whereby the local ARM data sets can be incorporated into broader spatial analyses. The CPM WG must engage other WGs in order to define and produce integrated data sets aimed at the evaluation of cloud and radiation parameterizations. The Infrastructure plays a key role here.

- A partial solution to the problem of accurately specifying the lateral boundary conditions for use with CPM WG models is to use ensembles of simulations of both SCMs and CRMs using specified small variations in the boundary conditions based on the expected uncertainty. Such ensembles can provide measures of the uncertainty in the model results due to uncertainty in the lateral boundary conditions.

- Organize IOPs to address specific parameterization problems. Put more emphasis on processes (both measurement and mathematical description) in the context of their parameterizations in GCMs.

- ARM needs to more successfully fund the right proposals; the program needs to shift the mix towards more *science-oriented* rather than product- or technique-oriented research. ARM should be a scientific enterprise more than an engineering enterprise.

- The CPM WG should be using CRMs much more as platforms for getting information about subgrid statistics, rather than just verifying that they do better than SCMs. In addition, the CPM WG should use CRMs more effectively as links between local ARM observations (such as those from the MMCR) and SCMs. CRMs can be sampled in a way that is directly comparable to point measurements. This is especially relevant for testing cloud parameterizations, because cloud properties such as IWC can at present only be retrieved under special local conditions (such as thin cirrus with no lower clouds). We also need to capitalize on the fact that CRMs are inherently more realistic than SCMs, especially when an ensemble of CRM results is available.

- ARM needs to continue to be alert to opportunities to interact with other programs. As noted earlier, the program has done a good job of this already, but it needs to continue. For example, if ACPI (or some form of it) comes to life, ARM needs find a role for itself. In addition, it would be good if ARM could find a way to collaborate more visibly with the Community Climate System Model effort.

- The ARM Science Team needs to interact more successfully with the ARM Infrastructure, so as to clearly identify what is needed, and so as to direct Infrastructure resources toward tasks with high scientific payoffs.

- ARM needs to involve more scientists to determine relationships between cloud properties from ARM observations, to compare global cloud observations and GCM results, and to compare ARM CART point cloud observations with SCMs, CRMs, and NWP model results.

- Finally, the existing CPM WG alone certainly does not have all of expertise required to accomplish its own goals. We need bridges to the radiation community, people to test radiation parameterizations in SCMs, and people to process ARM radiation data to produce radiative fluxes and remote sensing-derived forcing. We need help from the ARM Infrastructure, help from other ARM WGs, and also from the larger research community. Bringing in a larger community does not necessarily mean expanding the size of the ARM Science Team. Alternatives include alliances (like the one we have with GCSS), initiatives like the ARM Fellows program, mini-contracts to support high-priority tasks that cannot be carried out efficiently by either the Science Team or the Infrastructure, and wider dissemination of user-friendly ARM data products.

4. How we can assess how ARM is doing?

- First and foremost, ARM is succeeding if excellent value-added data sets are produced, disseminated, and then *widely used* by the community.

- ARM is succeeding if ARM research improves our understanding of radiation and cloud processes and methods for their parameterization, by generating outstanding science questions.

- ARM is succeeding if, through ARM, better cloud and radiation parameterizations are developed.

- ARM is succeeding if ARM data products are analyzed (not just produced) so as to evaluate cloud and radiation parameterizations.

- ARM is succeeding if it impacts predictions of climate change.